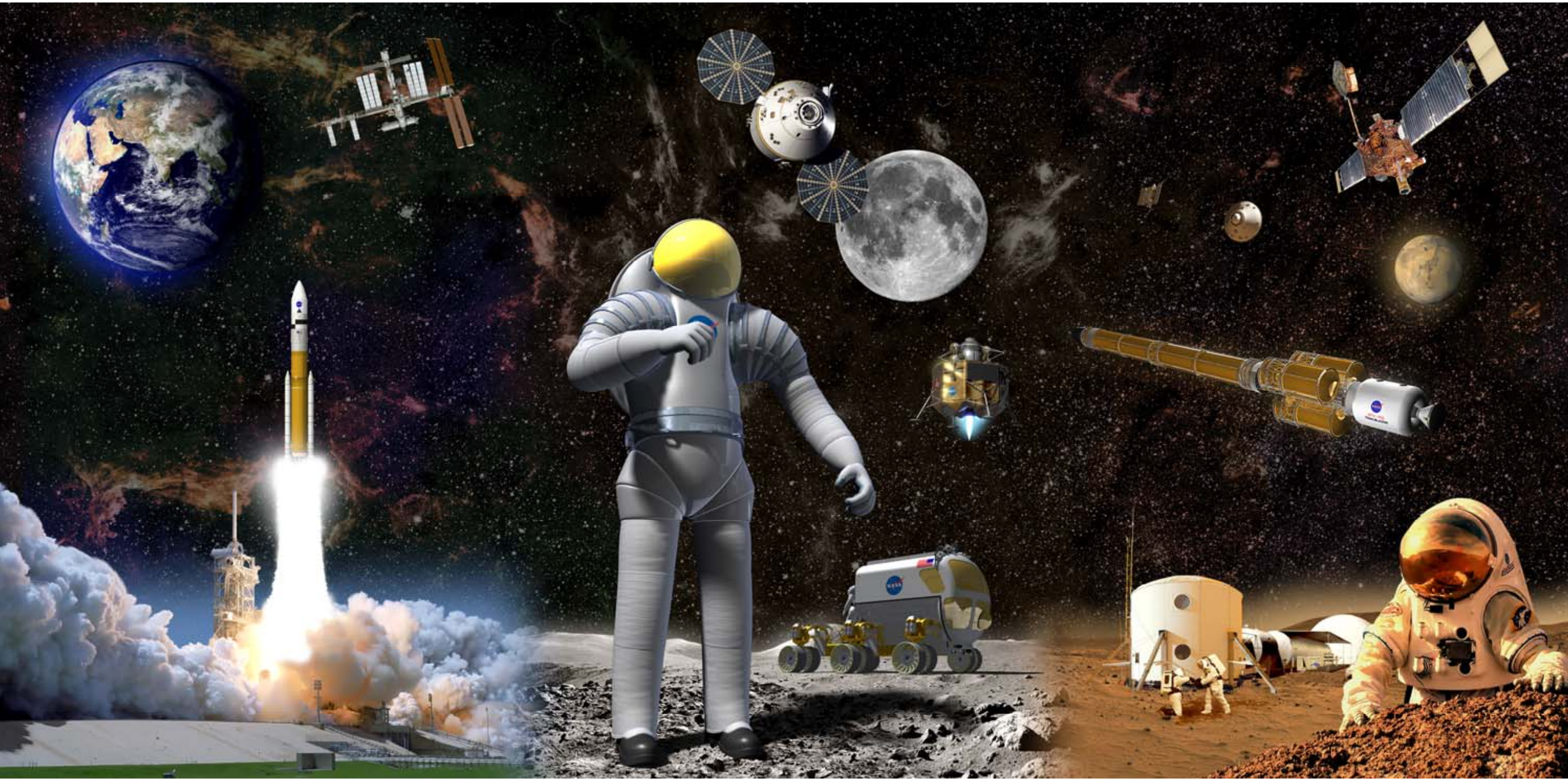
U.S. Chamber of Commerce Programmatic Workshop on NASA Lunar Surface Systems Concepts



Lunar Surface Systems Project Overview

Chris Culbert, February 2009

Introduction

- The Lunar Surface Systems Project Office was established in August of 2007 in the Constellation Program Office at JSC
  - Chris Culbert named Project Manager
  - Matt Leonard and Scott Vangen named Deputy Project Managers

Mission Statement

Develop a sustained human presence on the moon to promote exploration, science, commerce, and the United States' preeminence in space, and to serve as a stepping stone to future exploration of Mars and other destinations

Introduction (cont'd)

- Since forming, the LSS Project Office has focused primarily on supporting the ongoing agency work to define a viable Lunar Architecture, the framework for defining how to return humans to the moon.
- We have also provided a program level focus for ensuring that eventual Lunar surface activities are considered as the program progresses towards providing an Initial Capability for human transport.
- We have helped define technology needs and priorities and continue to work closely with the Exploration Technology Development Program.

Lunar Architecture Background

- NASA has completed multiple rounds of lunar architecture work looking at ways to provide the capabilities identified in the US Space Exploration Policy and expand upon the outline defined by the Exploration Systems Architecture Study (ESAS)
- The program passed one major lunar milestone in July 2008 with the Lunar Concept Capability Review (LCCR). At LCCR, Constellation demonstrated:
  - A transportation system that closed from a performance & cost perspective
  - A concept for a Lunar Outpost that was both technically feasible and consistent with the transportation system
  - An initial strategy on how to engage the commercial and international community for partnership options

Lunar Architecture Background

- The Lunar Outpost concepts had evolved over three years of conceptual work. Many options were considered and much progress has been made on identifying basic strategies.
  - For LCCR, a specific concept was developed in sufficient depth to demonstrate that a Lunar Outpost for long term science and exploration activities does not require significant technological breakthroughs and can be developed, with partners, at a reasonable cost

Post LCCR Lunar Surface Strategy

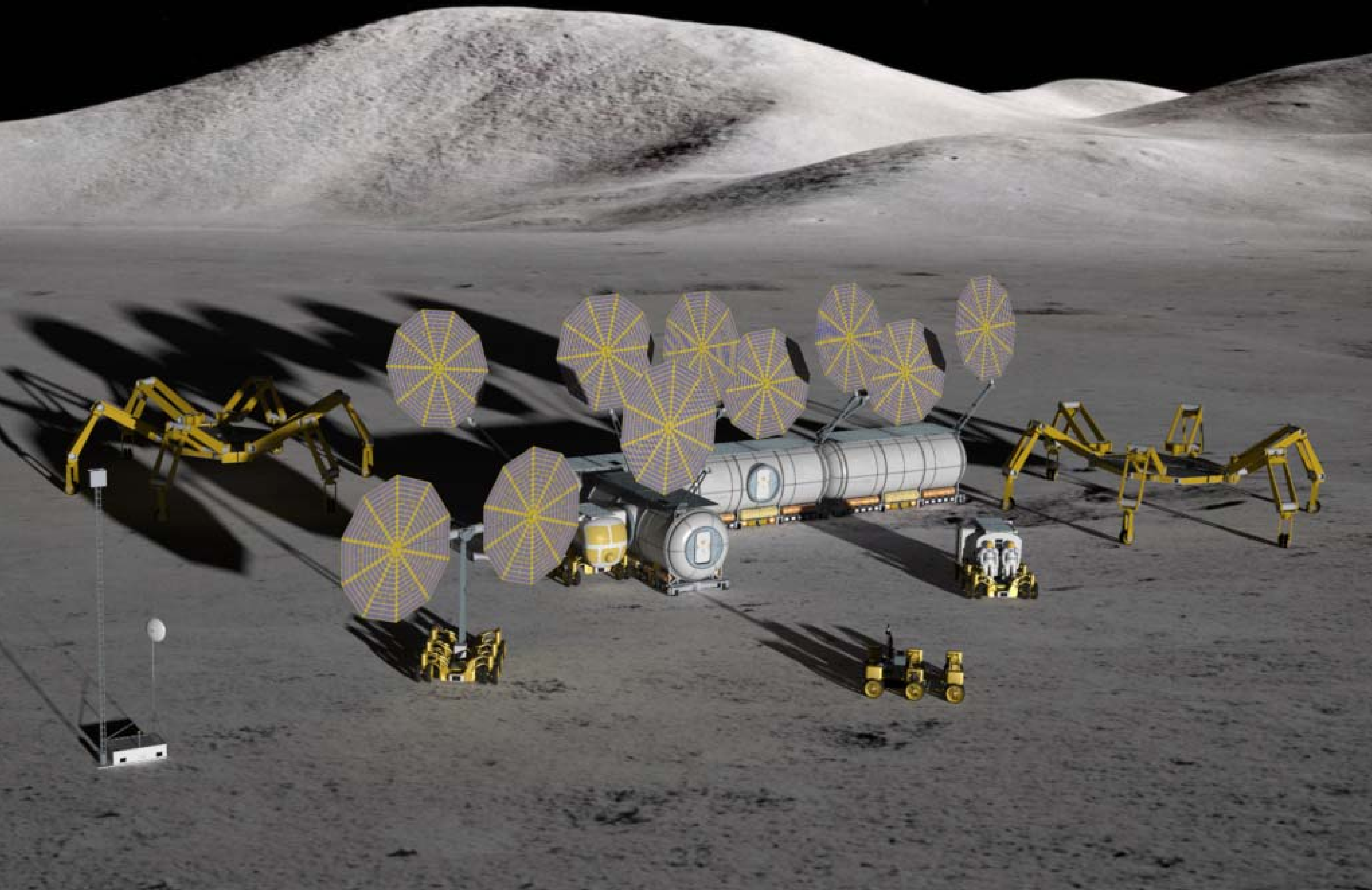
- Next major programmatic milestone for LSS is a review in mid 2010
- Significant focus on maturing International Partner relationships and discussion
  - NASA has proposed completing a Global point of departure Lunar Surface Architecture by June 2010
- Developing a broad set of reference missions defined and organized so as to allow comparison, analysis and framing of the trade space
  - Need to have enough breadth to enable both discussions about CxP contributions as well as partner contributions

Study Contracts

- A Broad Agency Announcement (BAA) was released in June 2008 which resulted in 12 small study contracts to pursue innovative concepts for the lunar surface infrastructure
  - Study contracts were completed in February 2009

- NASA would like to release a second LSS BAA to build upon the architecture work, to extend ideas from the first round of study contracts, and to open up additional areas to innovation.
  - Timing and size of the next BAA is currently under discussion
  - Topic list is also under review, though there will certainly be some new topics

Lunar Surface Architecture Information



Basic Outpost Capabilities

- Habitation systems that will support a crew of 4 for 180 days on the lunar surface
- Demonstrated ability to produce ISRU based oxygen at a rate of 1 mT per year
- Pressurized roving systems that can travel for hundreds of kilometers from the Outpost
- Power – at least 35 kW of net power production and storage for crewed eclipse periods
- Surface based laboratory systems and instruments to meet science objectives
- Sufficient functional redundancy to ensure safety and mission success

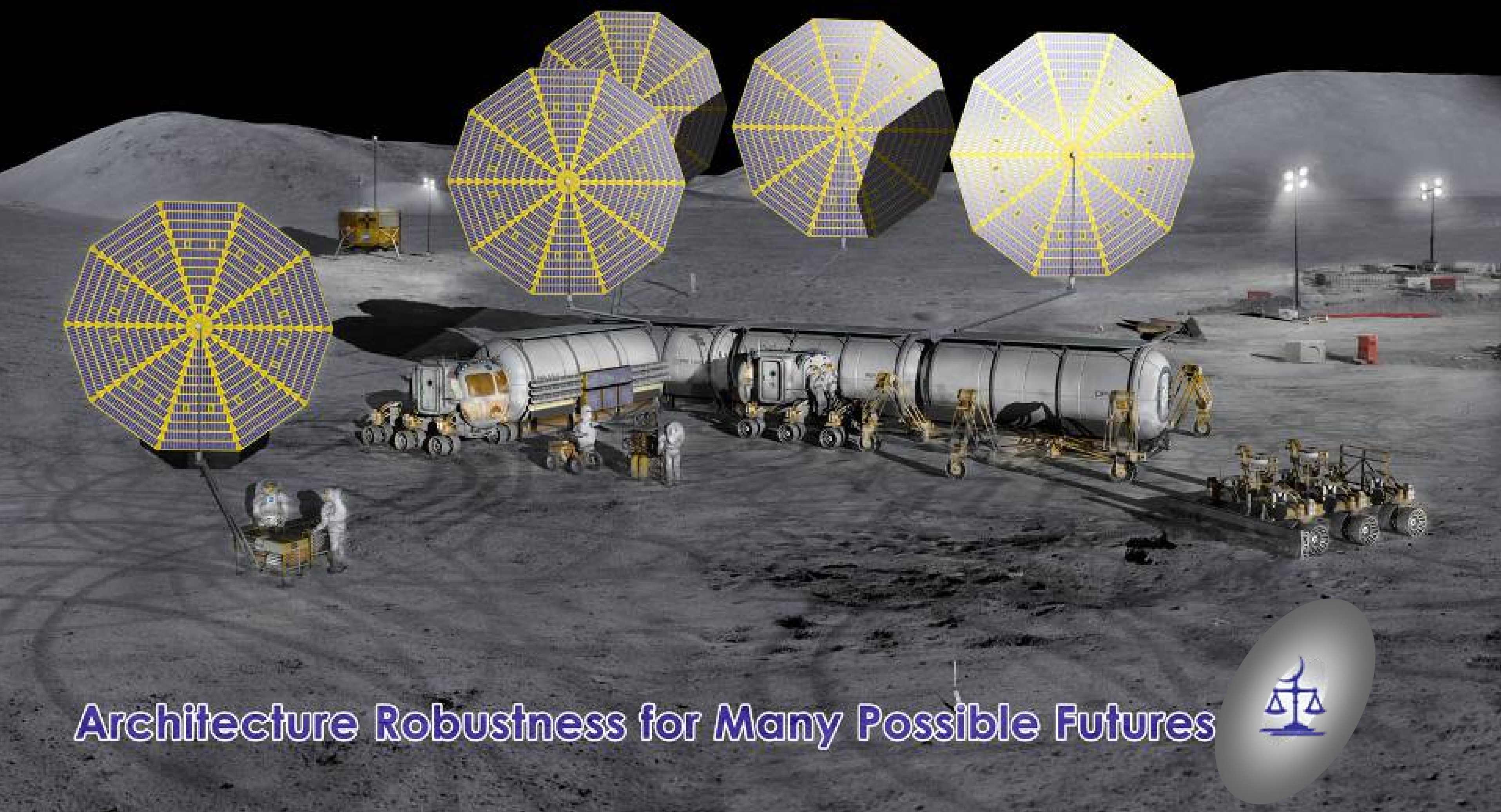
Caveat

- The Lunar Surface Systems Office is still in the stage of formulating and analyzing various architectures.
- All data contained herein is notional; there has been no selection of a "baseline" architecture at this time.
- No distinction has been made as to which assets may be provided by NASA, contractors, commercial entities, or international partners.

Lunar Surface Scenarios Families

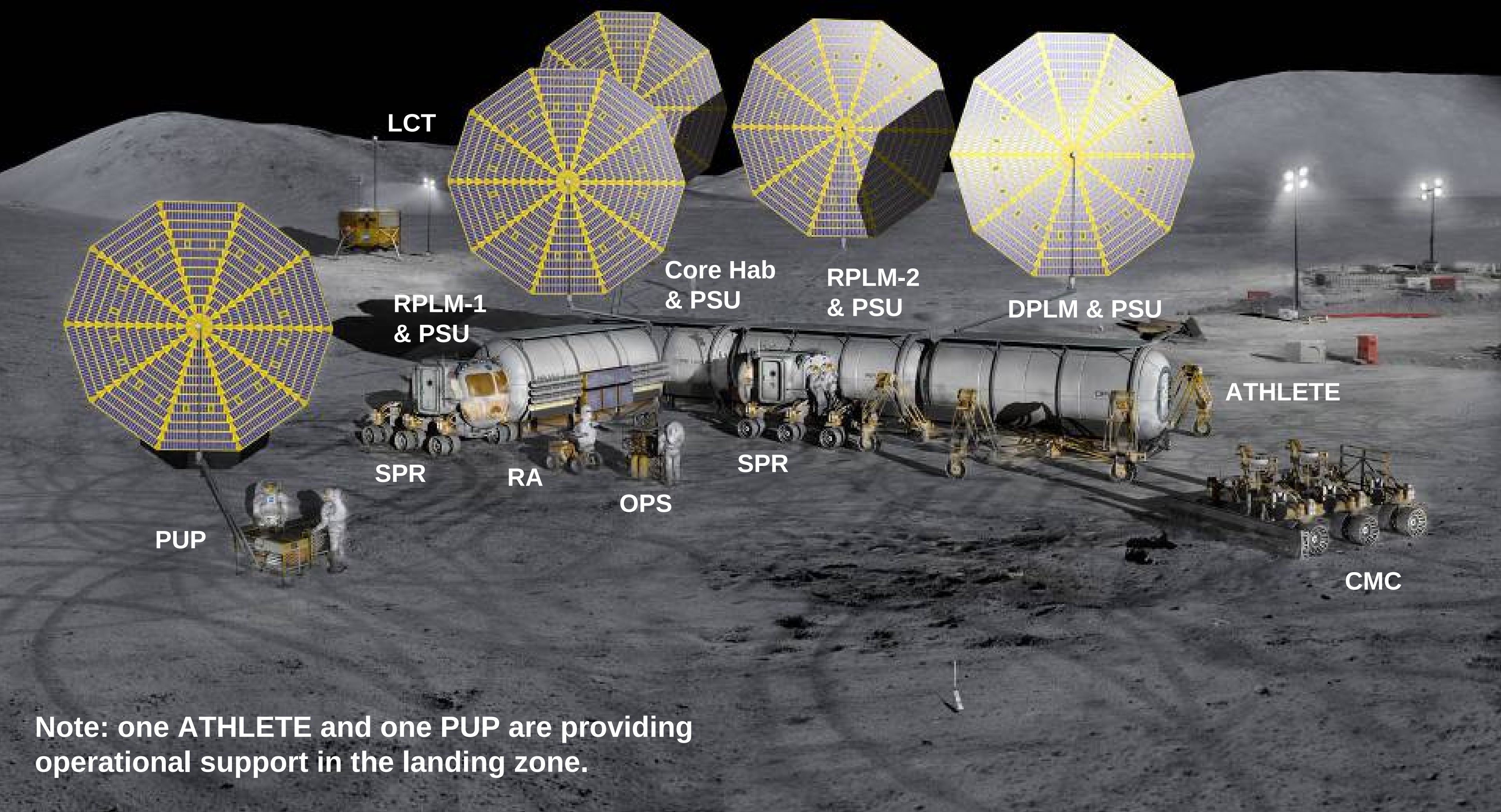
Scenario	Description
1	Full Outpost Assembly from LCCR (Trade Set 1)
2	Mobility oriented Outpost from LCCR (Trade Set 2)
3	Habitation oriented Outpost from LCCR (Trade Set 3)
4	Rebuild of LCCR scenarios increasing crew flights to at least 2 per year
5	Nuclear power based scenarios – Use a fission reactor as the primary power source
6	Power beaming scenarios – Consider ways to beam power from orbit or surface to systems
7	Recyclable lander – Scenarios that make massive reuse of lander components to build up the Outpost and surface infrastructure
8	Extreme mobility – Scenarios that deploy Small Pressurized Rovers early and use them as primary habitation
9	Improving Lander offloading – Scenarios that support a lander configured to make unloading much less complex
10	Refuelable lander – Scenarios that support a lander designed for multiple flights to and from LLO
11	Mars Centric – Scenarios that optimize Mars exploration ties

Scenario 4



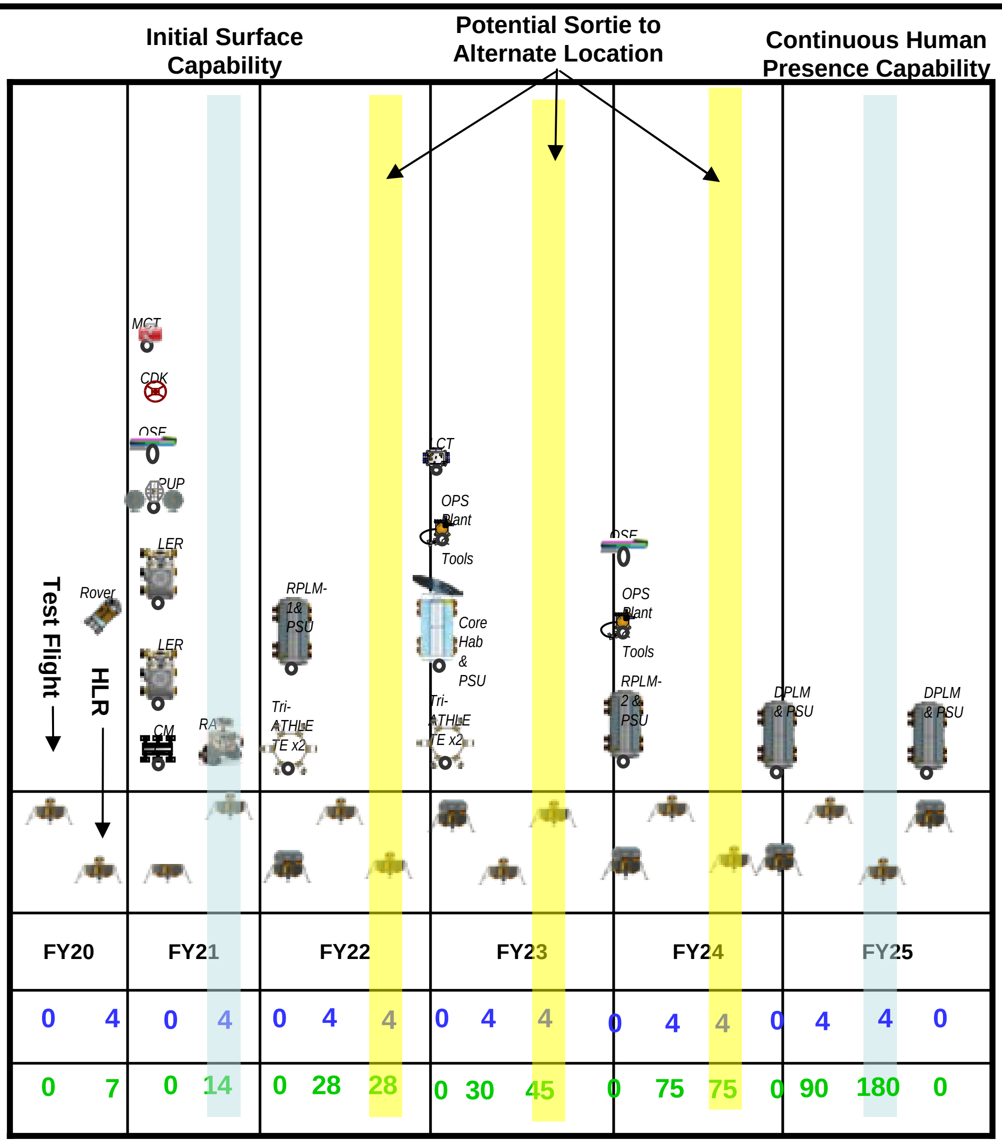
Architecture Robustness for Many Possible Futures

Scenario 4.2.1

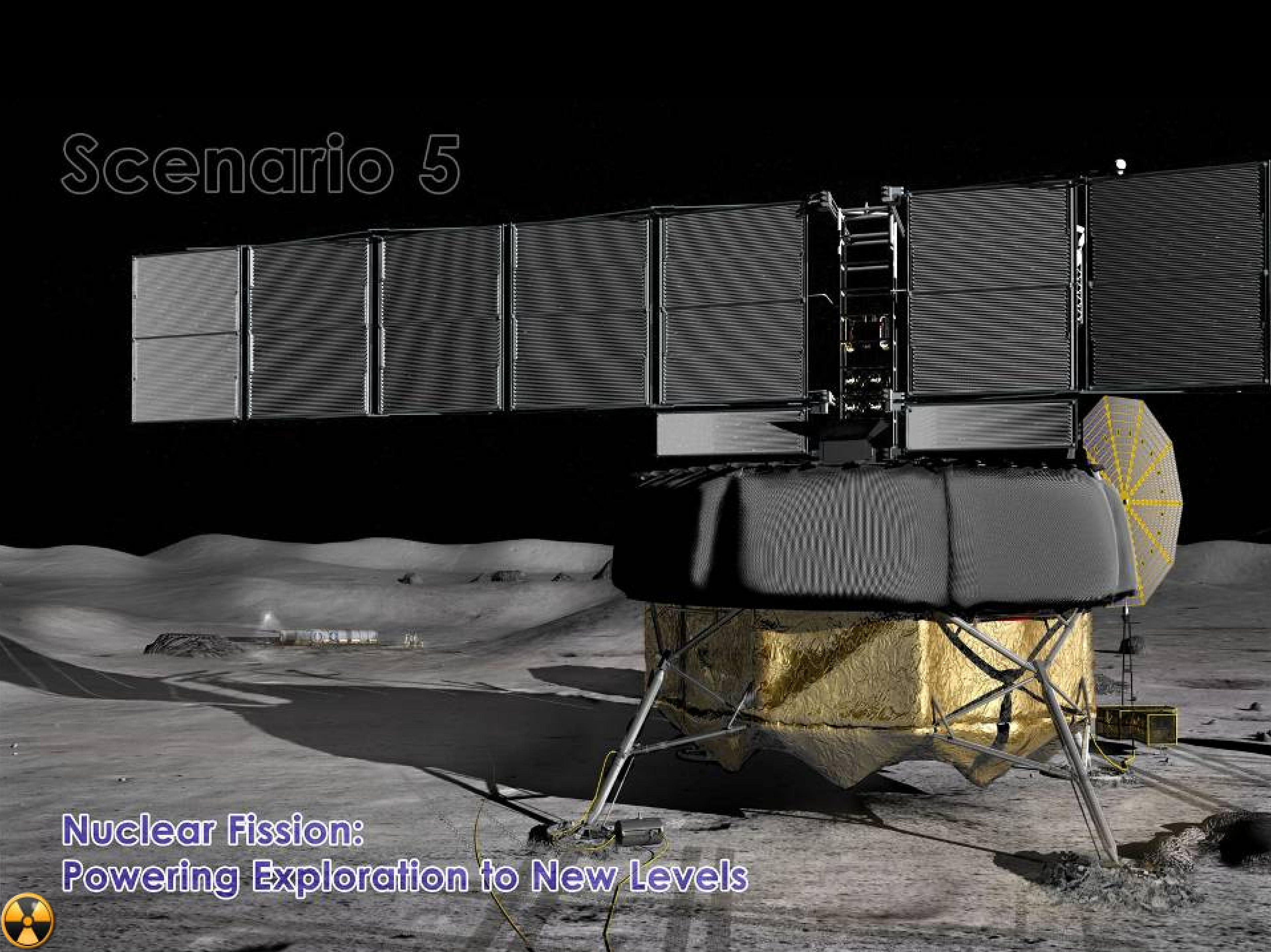


Note: one ATHLETE and one PUP are providing operational support in the landing zone.

Scenario 4.2.1.20 Manifest

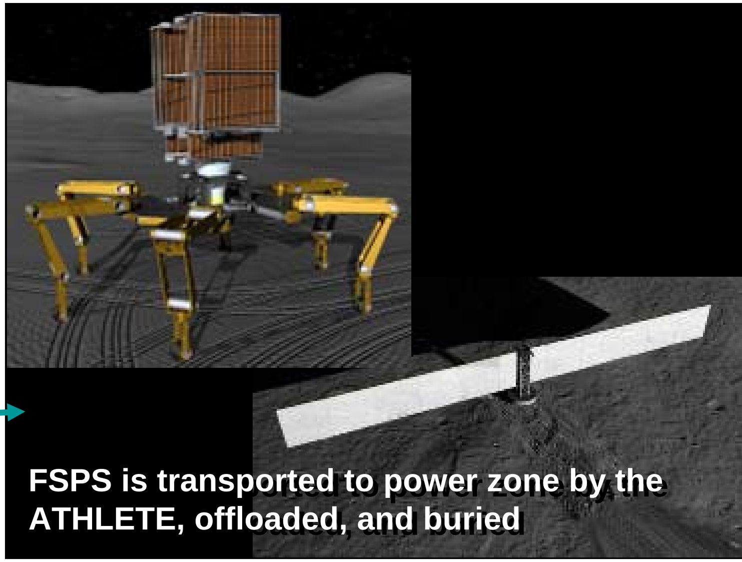


- Crew Size   # - Surface Duration

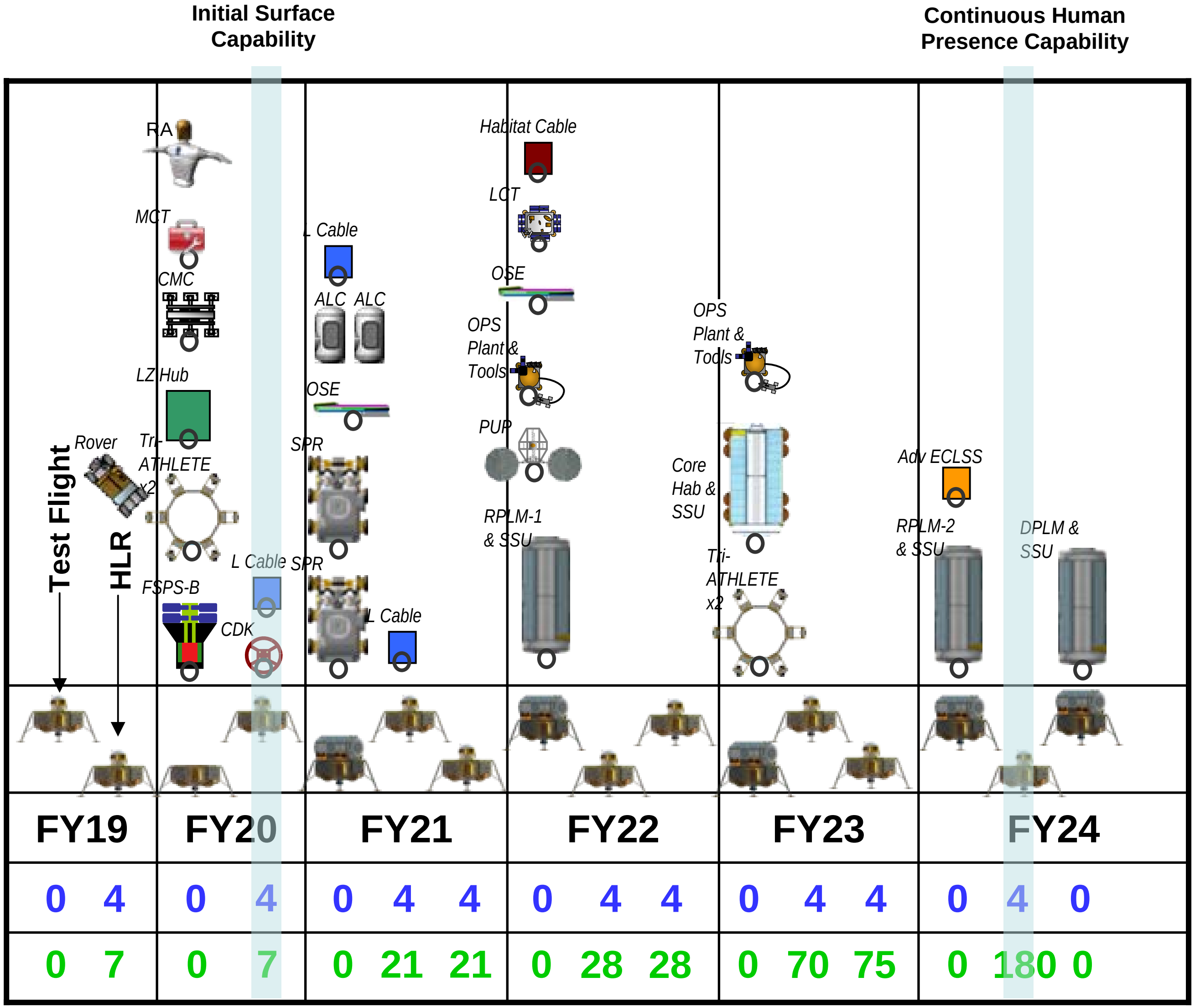

Scenario 5
Nuclear Fission:
Powering Exploration to New Levels

Scenario-5 Variations

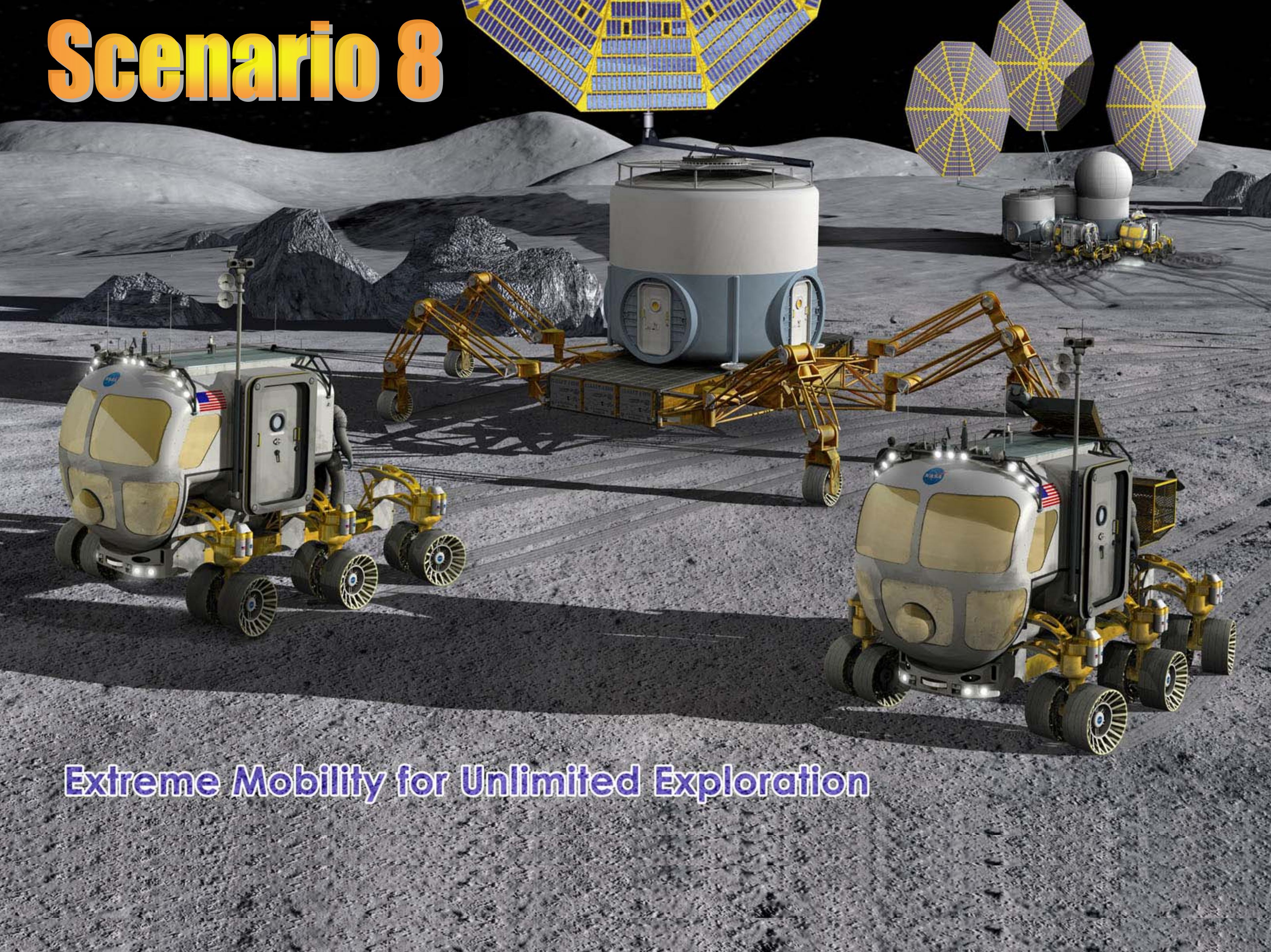
- Scenario-5 is very similar to Scenario-4, but it uses Fission Surface Power (FSP) instead of Solar for the primary power source.
- There are two alterations that were considered in terms of placement of the FSP:
  - Scenario 5.0.2: Off-Loaded & Buried
    - Lowest mass FSPS
    - Reactor can be located close to outpost (100 m)
    - Requires 2.3 m deep hole
    - ATHLETE digs hole; moves FSPS to site; places FSPS in hole
  - Scenario 5.1.0: Remains on Lander
    - Greater separation (400 m) to achieve same radiation level
    - Additional on-board shielding and power cabling results in greater system mass
    - Requires regolith fill in lander cavity surrounding reactor core and regolith “bags” around lander
    - Bladed rover collects regolith near lander; Crane scoops regolith and fills cavity and bags



Scenario 5.0.2 Manifest



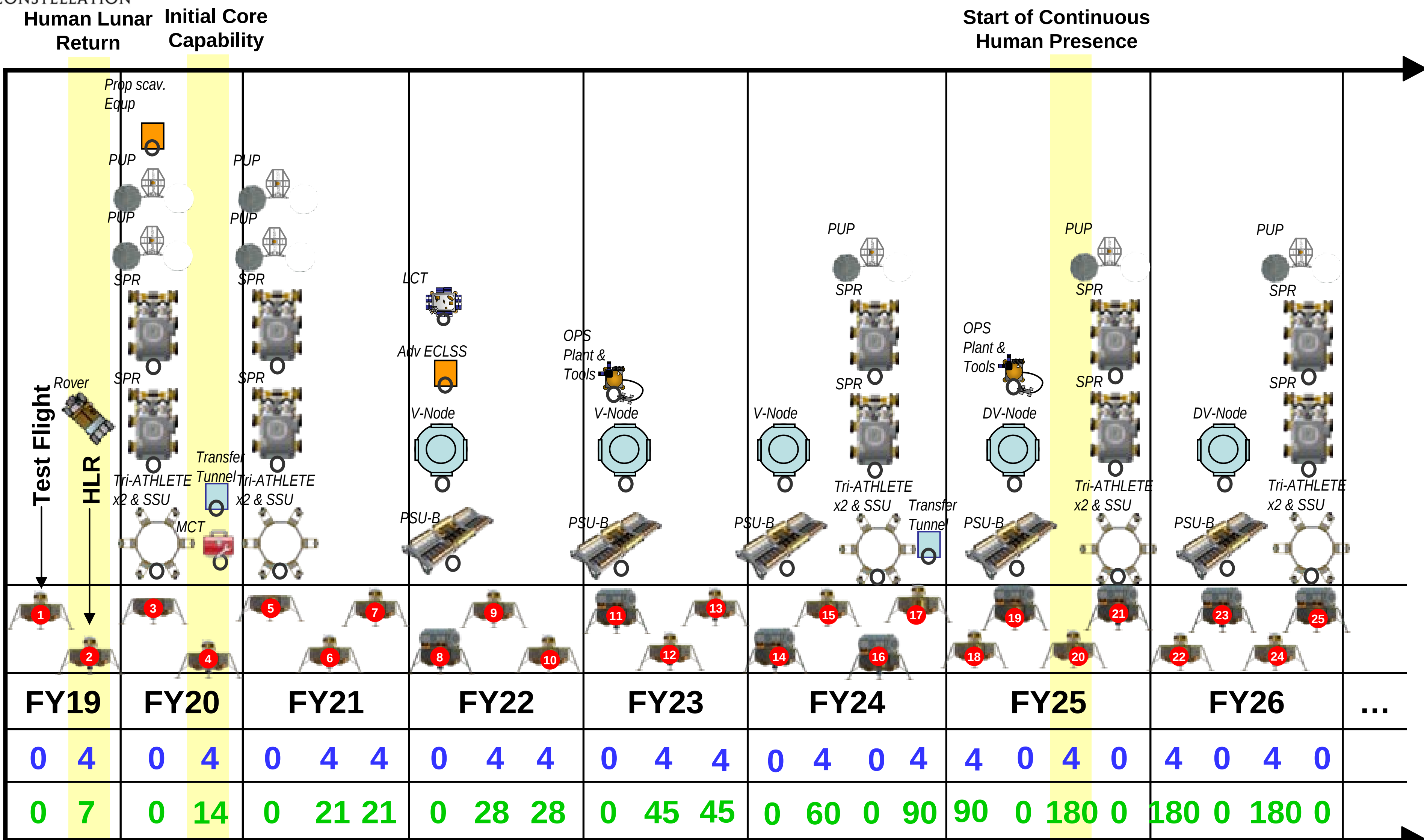
- Crew Size   # - Surface Duration


Scenario 8
Extreme Mobility for Unlimited Exploration

Scenario-8 Goal

- **Goal: Identify architecture opportunities that would increase *flexibility for costing* of the outpost buildup.**
  - *Power Approach*:
    - Assume all batteries for power.
    - Let advanced power storage *buy itself back in* due to function requirements such as mobility, continuous presence, etc.
    - Rationale: Identify timeframe by which development costs of power stowage can be postponed, thus potentially providing a more cost-effective scenario.
  - *Common Pressure Vessel Approach*:
    - **Scenario 8.0.0**: Investigate the impacts of using a single, common pressure vessel
      - SPR Cab chosen
      - Assess limitations in surface capability should delays occur in development of additional types of pressure vessels (larger habs, PLMs, etc.)
    - **Scenario 8.1.0**: Introduce a second type of pressure vessel in the manifest:
      - Investigate an alternate configuration to those considered in Scenarios 1-5.
      - Vertical Node (V-Node) configuration
        - Details in Section 2 (element functionality)

Sample Scenario 8.1.0 Manifest



- Crew Size # - Surface Duration # - Mission Number

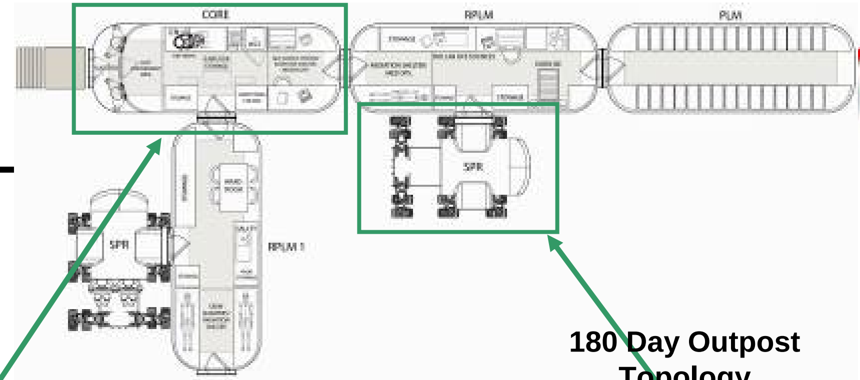
Element Functional Descriptions

Surface Habitation

CONSTELLATION

Functional Description:
The habitat elements provide a pressurized environment for the crewmembers to live and work while performing mission tasks on the lunar surface. The surface habitation main living area is comprised of a Core Habitat module which provides initial capability for 4 crew staying for up to 28 days. With the addition of 2 Reusable Pressurized Logistics Modules (RPLMs) which are retrofitted, and the Small Pressurized Rover (LER) crew cabins, 4 crew then have the capability to stay for up to 180 days, forming the foundation for the lunar outpost. The surface habitation elements support all aspects of IVA and EVA operations. Additionally, Disposable Pressurized Logistics Modules (DPLMs) provide IVA access to logistics supplies and spares.

- Supports a crew of 4
- Mission duration: up to 180 days (210 with contingency)
- Al-Li hard shell module - 3.0 m diameter x 8.35 m length with ~55 m^3 of pressurized volume per module
- Total maximum volume = ~242 m^3
- Core Habitat & RPLMs each have 3 connection ports
- DPLMs have 1 connection port
- Core Habitat has single airlock/suitlock
- Mass: Core Hab = 8.7 t; RPLM-1 = 4.3 t; RPLM-2 = 4.9 t
- Average Active Operating Power: Core Hab = 5.9 kW; RPLM-1 = 1.3 kW; RPLM-2 = 2.9 kW
- Core Habitat and RPLMs delivered with logistics to support crewed missions



180 Day Outpost Topology

Core Habitat

LER crew cabin

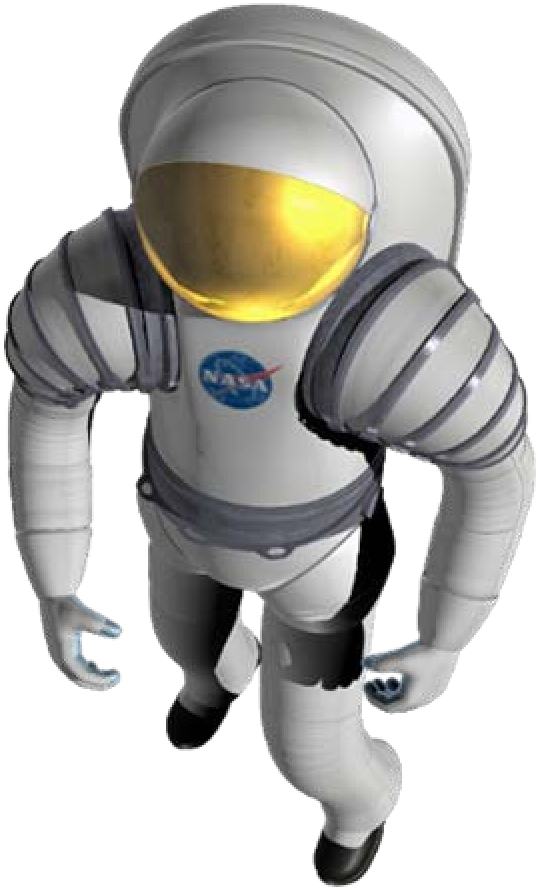
Outpost Configuration

EVA Suit

Functional Description:

Enables crewmembers to perform extravehicular activities (EVAs). Utilizes two pressure garment cores - one for Altair lander and lunar surface operations and the other for Orion operations. Additional hardware beyond the pressure garment required for lunar surface operations are portable life support subsystem (PLSS), Recharge and Buddy umbilicals, helmet camera, EVA visor assembly, EVA System servicing equipment, and general EVA tools.

- Nominal EVA Suit operating pressure = 30 kPa (4.3 psi)
- Rear-entry design
- PLSS designed for 8 hours of independent operations
- Maintenance on suits every 28 days

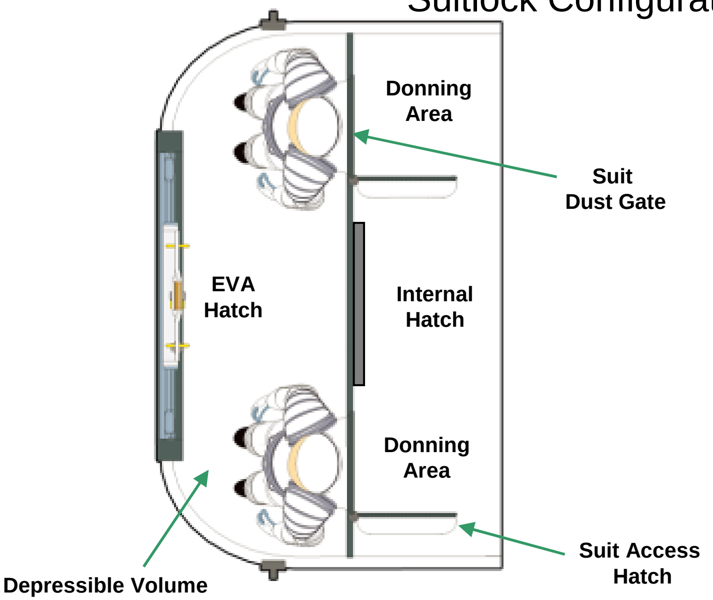


Airlocks & Suitlocks

Altair Lander Airlock

A two person airlock allowing crewmembers to conduct EVAs on the lunar surface during sortie missions.

- 90% gas recovery
- Enables daily EVAs during a sortie mission
- Airlock volume = 5.5 m^3



Core Habitat Suitlock

Functionality is similar to the two person airlock except that there are two suit dust gates for dust mitigation and two suit access hatches.

- 90% gas recovery
- 3 EVAs per crewmember per week
- Max of 24 hours of EVA per crewmember per week
- Suitlock volume = 6.5 m3

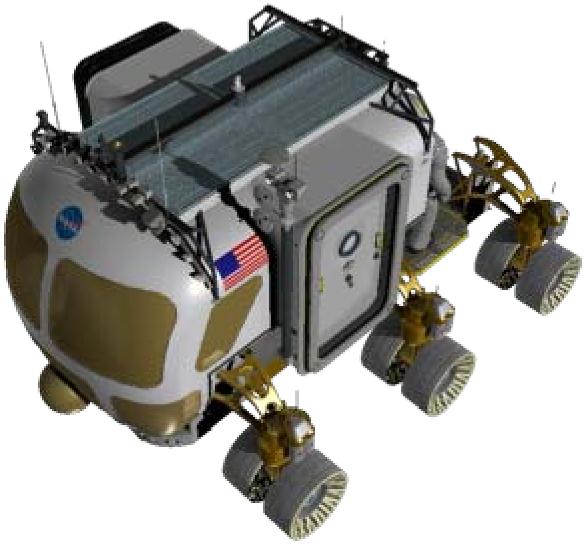
Lunar Electric Rover (LER): a Small Pressurized Rover (SPR) Concept

Functional Description:

Each LER provides a mobile pressurized environment for a two person crew on extended exploration and scientific operations or for a four-person crew in contingencies. Comfortable shirt-sleeve, sensor augmented environment for gross translations and geological observations reduces time in EVA suit and extends exploration range and productivity. Suitports enable rapid egress to the planetary surface and rapid ingress to the shelter of the rover in emergencies while enabling significant savings in crew time and consumables. Two common hatches provide docking and transfer under pressure with habitat, logistics elements and possibly lander, which may eliminate need for a lander airlock. A fusible heat sink provides thermal management and SPE radiation protection while roving on surface. Using each other as backup, two LERs enable 2 x 2-person crews to explore up to 1000 km from the lander / outpost with additional logistics and power augmentation.

Specifications

- Range = 100 km (3 days), 1,000 km (14 days)
- Mass = 2,952 kg (excluding chassis)
- Crew = 2 (4 in contingency)
- LER cabin pressure ~55 kPa (8 psi)
- Excursion duration = 3 days nominal extended to 14 days with Portable Utility Pallet
- EVA driving station enables operation as a UPR
- Environmental shelter protects suits while attached to suitports
- LER recharges PLSS when stowed. LER recharges ECLSS when attached to RPLM.

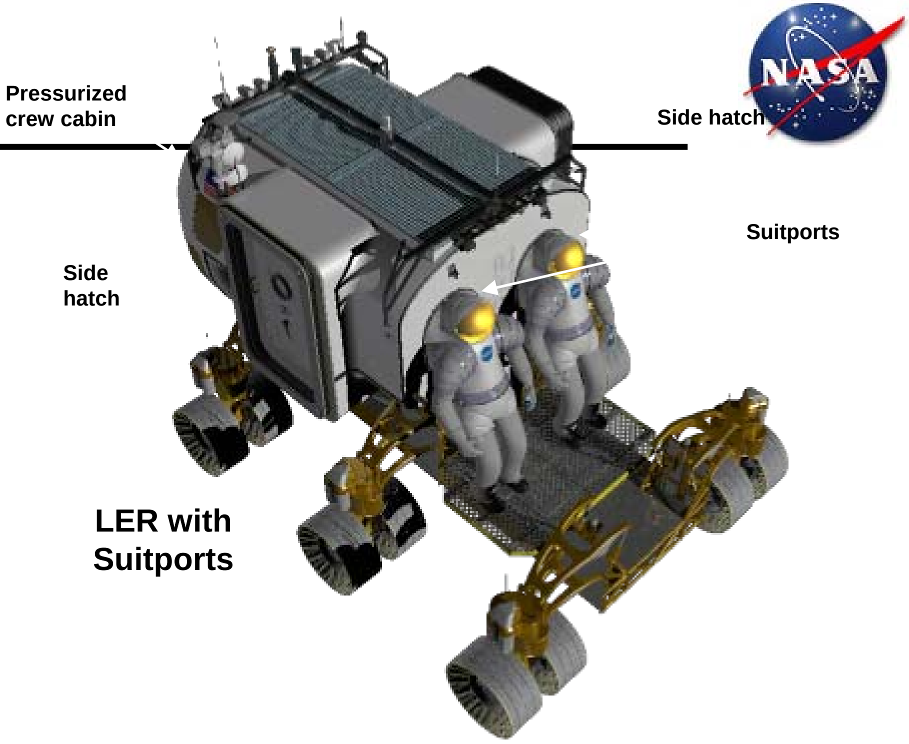


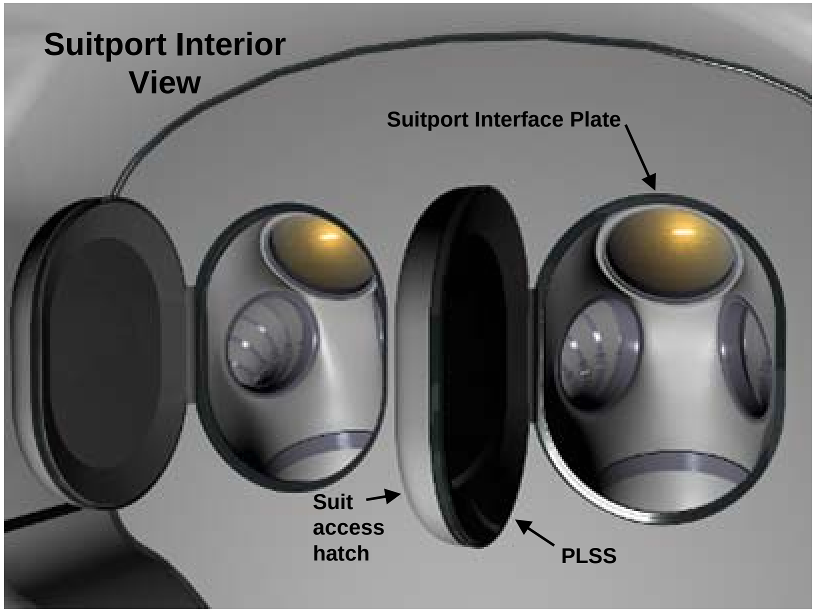
LER Suitport Concept

Functional Description:

PLSS-in-hatch design provides quick crewmember egress and ingress from LER, facilitates incapacitated crew recovery, and serves as a pressure barrier between habitable volume and vacuum.

- 2 full cycles per suit port per day,
  1 cycle = full egress & ingress
- 24 EVA hours max per week per crewmember
- Suit ingress/egress time: ~10-15 min
- Emergency ingress via side hatch





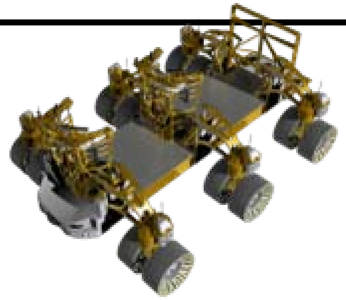
Crew Mobility Chassis (CMC)

Functional Description:

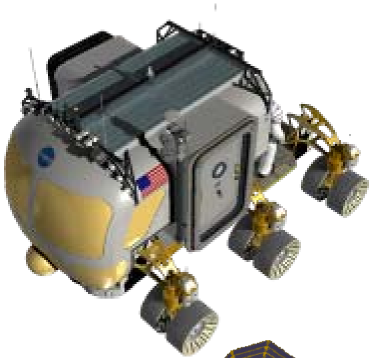
The CMC provides a mobile base for pressurized and unpressurized crew operations for up to four crew, mobile power, ISRU, and site preparation.

Chassis Specifications

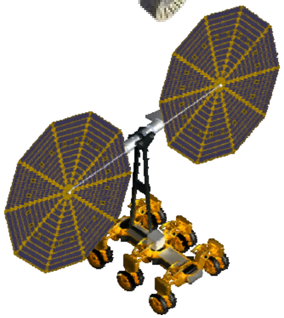
- 969 kg dry vehicle mass
- 3,000 kg payload
- >100 km range, upgradable with PUPs
- 0-5 kph low gear, 0-20 kph high gear
- 30° slope capability
- “Zero turning radius” crab drive
- Chassis leveling 0.75 m, +/- 10 degrees
- 20 kWh onboard energy storage (Li-ion battery)
- Driven onboard or remotely supervised



UPR



LER



Carrying PUP

Carrying ISRU

ATHLETE

The ATHLETE consists of two three-legged halves that combine with a PSU or SSU for offloading and long-duration excursions or with each other for operations around the outpost. Wheel-on-limbs design allows payloads to be directly “walked” off of lander deck 6+ m high at tilts of 12^{o} or more and over rough terrain with up to 30^{o} slopes. When carrying a pressurized living space and sufficient power, ATHLETE enables global exploration operations.

Specifications

- Mass: 2256 kg (complete ATHLETE)
- Payload: 14.5 t in three-legged iron cross
- Range is a function of available power
- 10 kph max speed
- At least 30° slope capability
- 6.5 kWh onboard Li-ion battery energy storage providing
- 5km travel with max payload before recharge
- 225Wh solar array for daylight operations and battery recharge
- Driven onboard or remotely supervised

Functional Description:

The Sortie Mission Chassis is a lightweight, four-wheeled rover similar to Lunar Roving Vehicle designed for sortie missions. It seats two crew members and can carry up to 490 kg. This element is new since LCCR.

Chassis Specifications

- 210 kg vehicle mass
- 490 kg payload
- 50 km max range
- 10 kph max speed
- 35° slope capability (payload dependent)
- 10 kWh onboard energy storage (Li-ion battery)
- Driven onboard or remotely supervised

Chassis A

Functional Description:

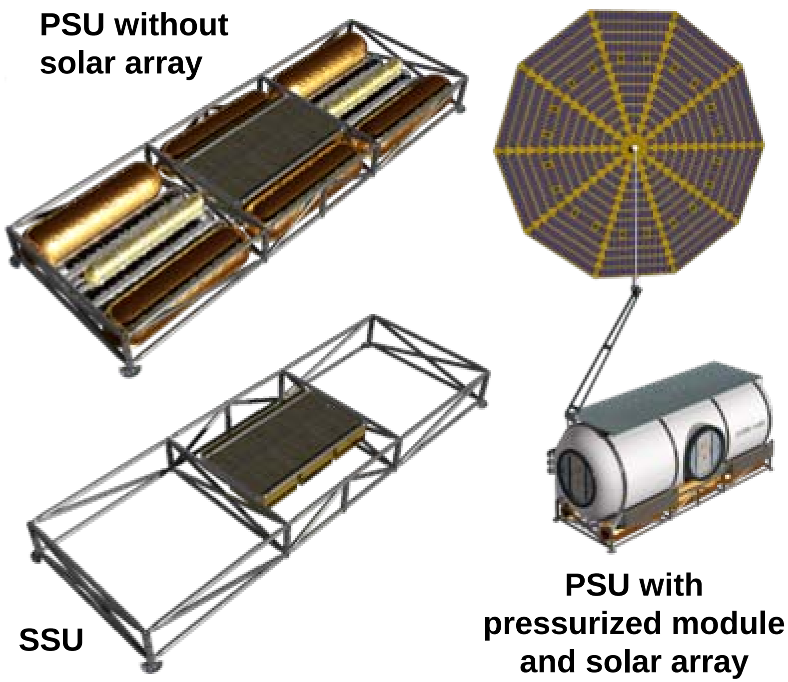
The Chassis A is a small four-wheeled vehicle designed to carry the Robot Assistant, a small version of an ISRU implement, or a sensor package. The chassis provides a workbench area for the robot assistant and a mount for tools, rock samples, or instruments.

Chassis Specifications

- 108 kg vehicle mass
- 100 kg payload
- 195 km max range
- 10 kph max speed
- 33° slope capability (payload CG dependent)
- 5 kWh onboard energy storage (Li-ion battery)
- Driven remotely supervised

Power & Support Unit (PSU) & Structural Support Unit (SSU)

The PSU provides a support structure and launch interface for cargo elements, and it carries the RFC power system that provides solar power generation and 720 kWh of energy storage for the outpost. Also carries an avionics and communications package to support outpost, a holding tank for scavenging water from landers, and provides structure to mount Habitat ECLSS and logistics resupply tanks. The composite structure works with a pressurized module or as a stand-alone unit, and can be configured without a power system as necessary (referred to as Structural Support Unit).



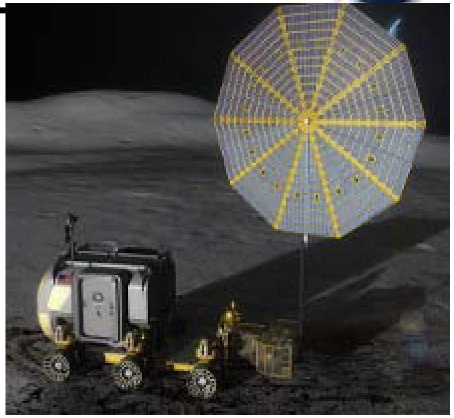
Specifications

- Mass: PSU 2,867 kg / SSU 680 kg
- Energy storage
  - 720 kWh Regenerative Fuel Cells
- Power generation
  - 9 meter array based on Orion design
  - 11.2 kW net solar array power
- Power consumables storage
  - 337 kg oxygen, 43 kg hydrogen; 450 kg water x 2 (power and scavenge)

Portable Utility Pallet (PUP)

The PUP is a small logistics pallet with a solar array and batteries that provides a mobile power and consumables source for excursions in an LER. The PUP can also provide lander keep-alive power and water scavenging services. The PUP is designed to interface with the CMC during delivery to the lunar surface and on surface excursions. The PUP can also be transported on the surface using ATHLETE. Each PUP can carry the additional gas and liquid consumables to extend excursions to 14 days for 2 crew (LER nominally provides 3 days).

PUP stowed on LER



PUP deployed

PUP attached to LER for use during excursion

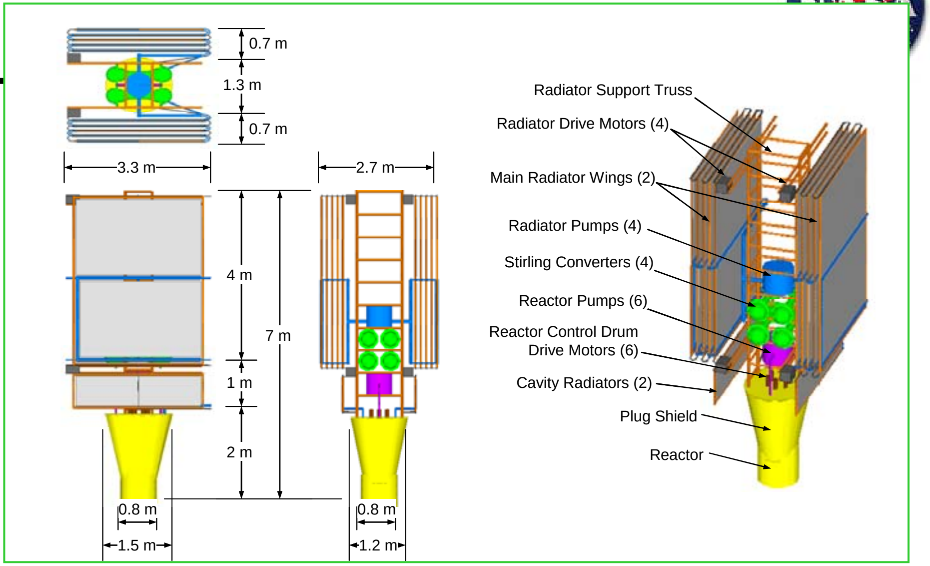
- Logistics:
    - Oxygen Capacity = 25 kg
    - Water Capacity = 90 kg
    - Wastewater Capacity = 90 kg
- Power Generation: 4.385 kW
    - 5.5 m diameter Orion-class solar array
- Energy Storage: 10 kWh (Li-ion batteries)
- Mass
    - Dry: 708.9 kg
    - Wet: 963.4 kg

Lander Integrated FSPS

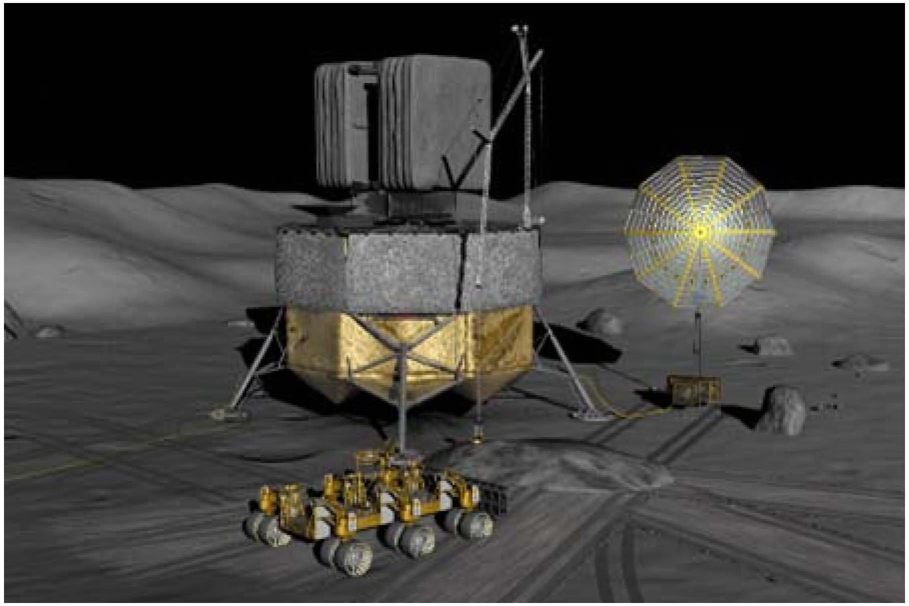
Functional Description:

Provide a single, centralized power source that can deliver continuous power for at least 8 years. Power management and distribution is provided by the Electrical Load Interface (ELI) located at the outpost. Shielding is enhanced by filling the lander cavity with regolith.

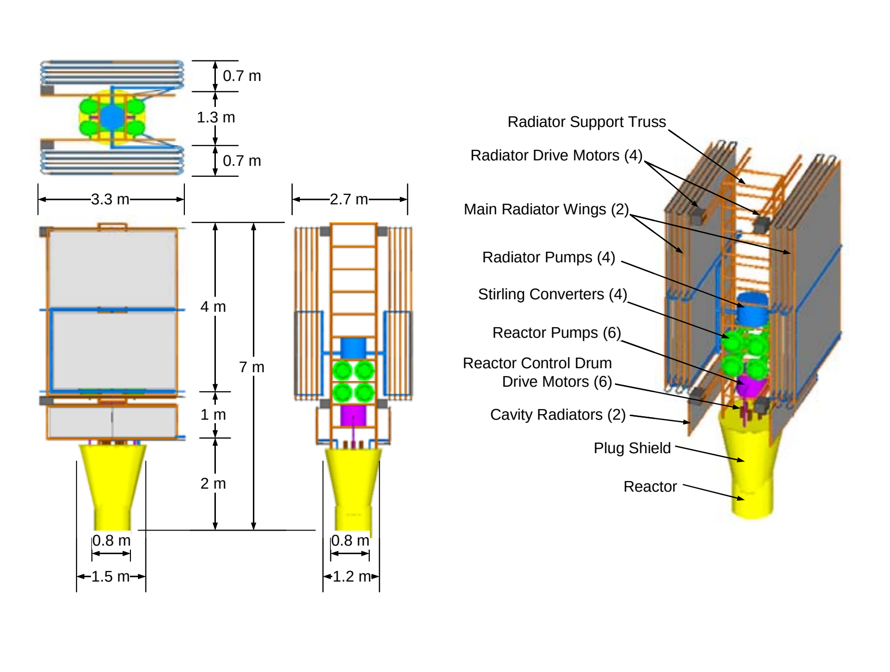
- Net Power Generated = 40 kW (daylight or eclipse)
- Total Mass =7,974 kg (includes shield, PMAD, cables)
- Distance for 3 mrem/hr dose to unshielded astronaut = 400 m
- Lander cavity regolith fill and external regolith bags augment delivered H_2O shield



FSPS fits into the Ascent Module engine bell cavity on Altair Descent Module. The cavity is filled with regolith on the surface.



Buried FSPS

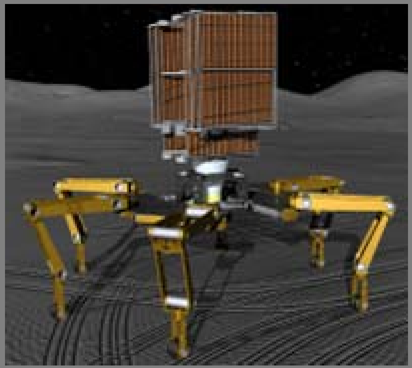


Functional Description:

Provide a single, centralized power source that can deliver continuous power for at least 8 years. Power management and distribution is provided by the Electrical Load Interface (ELI) located at the outpost. Shielding is enhanced by burying the FSPS in 2.3 m of regolith.

- Net Power Generated = 40 kW (daylight or eclipse)
- Total Mass = 6,902 kg (includes shield, PMAD, cables)
- Distance for 3 mrem/hr dose to unshielded astronaut = 100 m
- Burial in Regolith augments delivered B4C shield

FSPS is buried 2.3 m deep in lunar regolith



FSPS is transported to power zone by the ATHLETE

Robotic Assistant (RA)

Functional Description:

The Robotic Assistant has a two-jointed waist, allowing the arms to bend down to reach the ground, as well as swivel around and work with items on the chassis. The hands are five-fingered and dexterous, eliminating the need for specially designed gripping interfaces. The RA has a common interface enabling it to mount to any vehicle chassis or ATHLETE.

Specifications

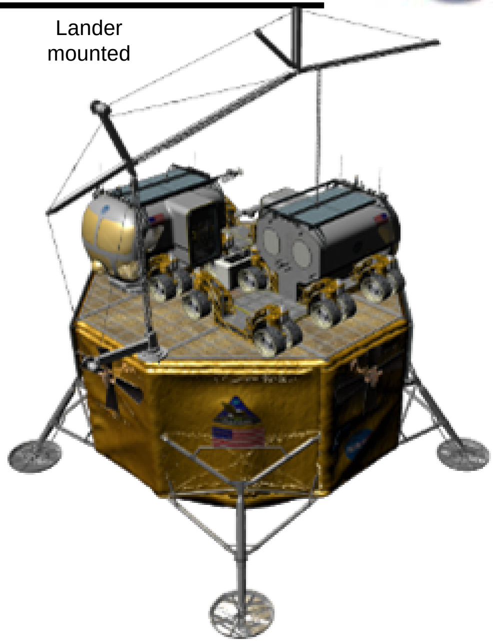
- Mass: 108 kg
- Arm Strength: ~50 kg (1/6g) at full extension
- Finger Strength: ~12 kg (1/6g)
- Waist Rotation: -360° to 360°
- Waist Tilt: -60° to 90°
- Neck Rotation: -360° to 360°
- Neck Tilt: -60° to 60°

Lunar Surface Manipulator System (LSMS)

Functional Description:

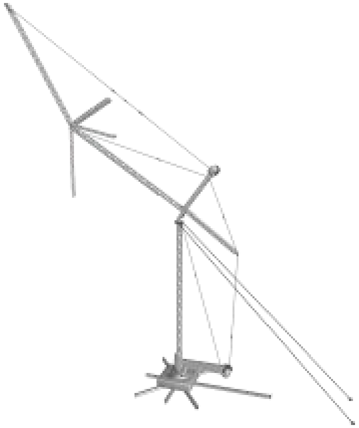
The LSMS provides 6 metric ton lift capability at full reach to offload payloads from lander deck and manipulate payloads on the lunar surface. The LSMS can mount to the lander deck, vehicle chassis, or on the lunar surface, and can move between them unaided. Interchangeable end effectors facilitate a variety of capabilities such as forklift-like operations, inspections, site preparation, and regolith handling.

Lander mounted

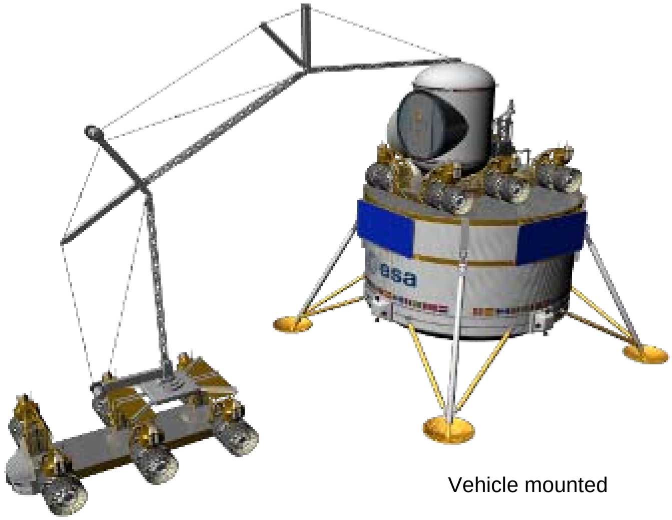


Specifications

Mass: 190 kg
Lift capability at wrist: 6 t
Lift capability at elbow: 10.4 t
Kingpost height: 3.75 m
Reach: 7 m



Surface mounted



Vehicle mounted

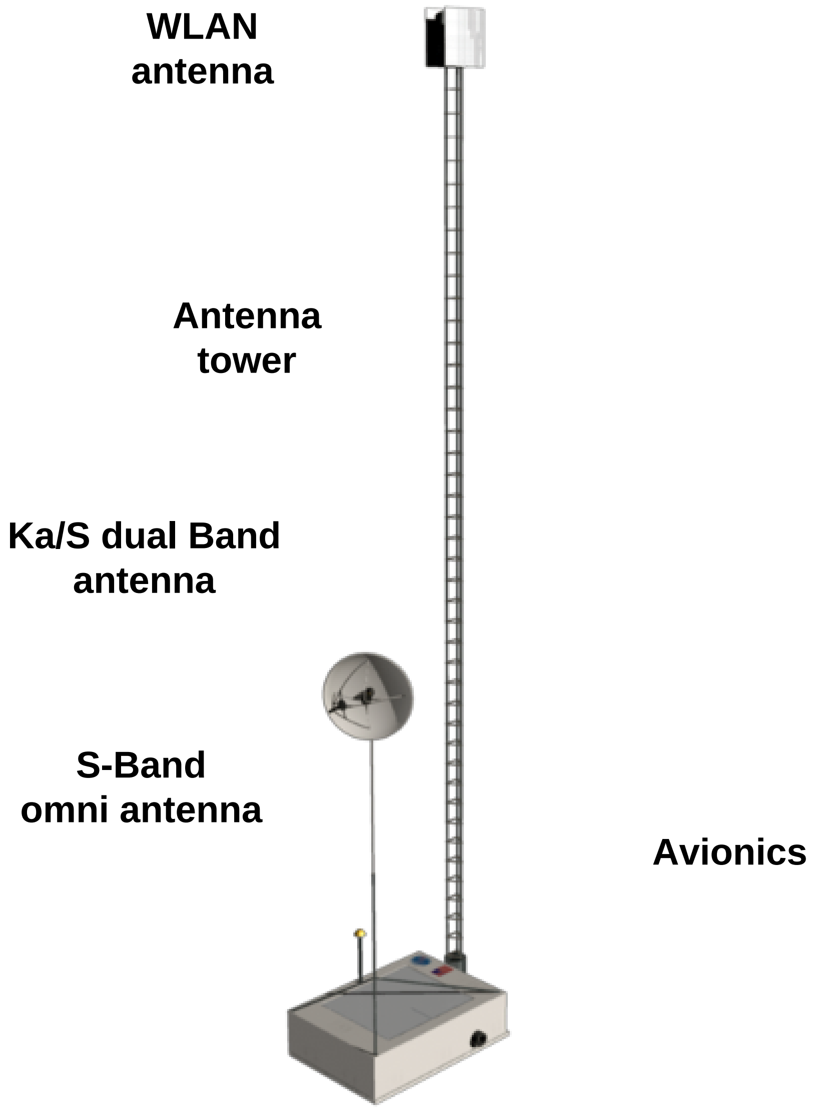
Lunar Communications Terminal (LCT)

Functional Description:

The LCT provides a communication hub for the lunar surface. The services of LCT are gateway services (low and high data rates)
data delivery to Earth via Lunar Relay Satellite (LRS) (primary) or via Direct to Earth (DTE) (secondary); surface wireless services; hardwire communication; data storage; local time; and routing.

Specifications

- 80 Mbps WLAN for lunar surface, 5.8 km range
- 200 Mbps Ka band Return Link (26 GHz) to LRS or Earth
- 100 Mbps Ka band Forward Link (23 GHz) from LRS or Earth
- 3 Mbps S-band Return Link (2.2 GHz) to LRS or Earth; 24 kbps safe mode
- 3 Mbps S-Band Forward Link (2.0 GHz) from LRS or Earth; 24 kbps safe mode
- 150 Mbps bi-directional fiber connection
- Mass: 417 kg
- Power required: 421 W (Nominal)



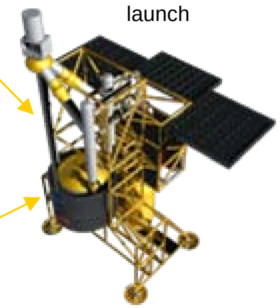
Oxygen Production System - ISRU

Functional Description:

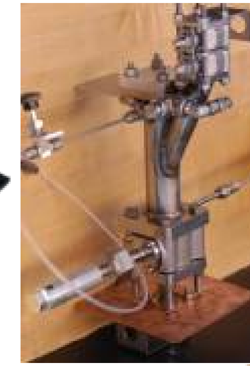
Perform lunar regolith excavation and handling, oxygen extraction from regolith, and oxygen storage and delivery. Supports lander propellant scavenging and water production. For flexibility, two 1/2-scale Oxygen Production Systems (OPSs) will be delivered and 2 sets of excavation tools.

- Total O_2 produced per plant = 500 kg/yr (solar) & 600 kg/yr (nuclear)
- Mass per O_2 plant = 219 kg
- Power required per plant = 3.93 kW
- Total regolith per plant = 208 kg/day
- Excavation tools = 42.7 kg (each)
- Excavation time = <1 hr/day

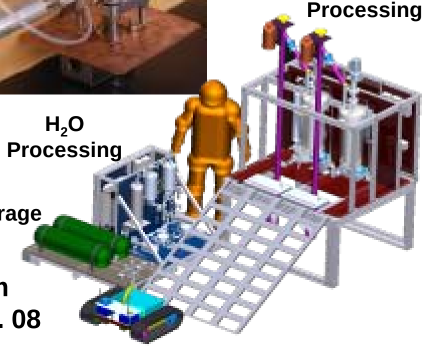
Oxygen Extraction from Regolith



TS 2/3 O_2 Production System with Storage and Thermal Control

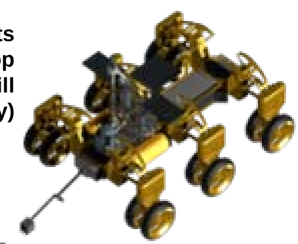


RESOLVE Subscale O_2 Extraction and Volatile release reactor



1st Gen O_2 Production System (660 kg/yr) for Field Demo, Nov. 08

Regolith Excavation and Movement



Excavation and O_2 Plant mounted on mobile chassis

Area Clear Blade on CMC

Cratos Excavator

Bucketwheel Excavator

1 t of oxygen per year requires a regolith excavation rate of <1/2 cup per minute! (1% efficiency - 70% light)

Acronyms

Acronym	Name	Function
ATHLETE	All-Terrain Hex-Legged Extra-Terrestrial Explorer	Surface Mobility
CDK	Chassis Driving Kit	Surface Mobility
CMC	Crew Mobility Chassis	Surface Mobility
DPLM	Disposable Pressurized Logistics Module	Logistics & Supportability
LCT	Lunar Communications Terminal	Communications
LER	Lunar Electric Rover	Surface Mobility
MCT	Mobility Chassis Toolkit	Site prep/science
OPS	Oxygen Production System	ISRU
OSE	Offloading & Support Equipment	Surface Operations and Unloading
PSU	Power & Support Unit	Power and Structural Interface
PUP	Portable Utility Pallet	Power
RPLM	Reusable Pressurized Logistics Module	Habitation, Logistics & Supportability
SPR	Small Pressurized Rover	Extended Surface Mobility
SSU	Structural Support Unit	Structural Interface